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STANDARD ELECTRONIC MODULE RADAR LIFE CYCLE COST STUDY.(U)

JUL 77 T R CORK, R H BLAZEK F33615-76-C-1336

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STANDARD ELECTRONIC MODULE RADAR LIFE CYCLE COST STUDY

BATTELLE'S COLUMBUS LABORATORIES
505 KING AVENUE
COLUMBUS, OHIO 43201

JULY 1977

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Final Report for June 1976 – November 1976

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This final report was submitted by the Columbus Laboratories of the Battelle Memorial Institute, Columbus, Ohio, under contract F33615-76-C-1336, job order 60960581, with the Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. Neil DiGiacomo was the Government Project Engineer. Mr. Thomas R. Cork was the Battelle Program Manager and also responsible for the life cycle cost analysis. Other contributors at Battelle included Robert H. Blazek, George J. Falkenbach, Loren L. Albrechtson, and Eugene N. Wyler.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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ABSTRACT

The Standard Electronic Module Program (SEMP) has been employed as a standardized design technology and logistics support concept by the U. S. Navy since 1962. From its original usage in shipboard systems, development of the SEMP has expanded to other electronic missions and to other services. The U. S. Air Force Avionics Laboratory initiated in 1974 an effort to evaluate the use of SEMP technology in the Air Force's avionics scenario. Under AFAL funding, the Naval Avionics Facility - Indianapolis has designed and fabricated an airborne weather-beacon-navigation radar system. Officially identified as the AN/APS-129, this radar is designed to perform the same function as the APN-59/B radar in C130, C135, and C141 aircraft. The purpose of this report is to present the results of an independent research program conducted to explore the benefits of SEMP technology as it is represented in the prototype APS-129 system. For analysis purposes, benefits are quantified in the framework of a retrofit program to replace the APN-59/B.

The findings of this research include:

(1) The APS-129 design, as an element of the Modular Radar Program, does demonstrate the feasibility of inter-service, inter-system commonality of functional electronic modules.

(2) The SEM concept offers design and logistic engineers a flexible alternative to design concepts which require specifying discrete components that are susceptable to technological and economic obsolescence.

(3) Weight and volume penalties are incurred by incorporating SEM's but these should be evaluated for the system level impact on a case-by-case basis and not cause automatic rejection of the technology.

(4) The analysis of the APS-129 design indicates that life cycle costs can be focused into cost categories which are not maintenance manpower sensitive.

(5) The APS-129 design demonstrates that the interface of module level commonality with line replaceable unit (LRU) modularity requires further investigation. This interface impacts LRU exchangeability (important in retrofit applications) and the definition of functionally common SEM's (important to maintenance and logistics costs).

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SUMMARY

This report documents a study of the life cycle cost characteristics of the APS-129 radar design within the framework of a retrofit program. The high logistics support costs of tube-type avionic systems are generating interest in developing new technologies to reduce avionics life cycle costs. The APS-129 program was initiated by the Air Force Avionics Laboratory to assess the potential use of the U. S. Navy originated Standard Electronic Module Program (SEMP) in an Air Force avionics application. The APS-129 system has been designed and two advanced development sets have been fabricated for a flight test program.

In conducting this study, the design was evaluated using both qualitative and quantitative factors. These factors addressed three characteristics of the SEMP concept as embodied in the APS-129 program. These characteristics are:

(1) SEMP as a design technology

(2) SEMP as a logistics concept

(3) SEMP for use in an avionic retrofit application

Activities involved in this study included: collecting information on the SEM program; reviewing detailed APS-129 drawings and design specifications; conducting an independent reliability analysis of SEM's, discrete components and assemblies; estimating acquisition costs; and performing a logistics support cost analysis of the design.

In addition, two design alternatives were postulated. In the first, the built-in test equipment was removed from each set of installed equipment but retained in the intermediate shop level test equipment. This reduced the estimated acquisition with a slight penalty in the support cost. The second design alternative evaluated the concept of allowing the major sub-assemblies of the receiver-transmitter, which consist primarily of SEMs, to be line replaceable units. It was estimated that this change would reduce the initial spares requirements (in dollars) and, potentially, provide a better interface of SEM's with existing Air Force Avionics maintenance and supply procedures.

Among the qualitative findings of this study, the following appear the most significant:

(1) The SEM concept offers design engineers and logisticians an alternative to design philosophies which require specifying discrete components. The SEM concept has advantages when considering the consequences of technological and economic obsolescence of discrete components. However, when considering weight, volume, and design flexibility, the SEM concept has some disadvantages.

(2) The APS-129 design demonstrates the feasibility of inter-service, inter-system commonality of functional electronic modules.

(3) The APS-129 design demonstrates that the interface of module level commonality with line replaceable unit (LRU) modularity requires further investigation. This interface impacts LRU exchangeability (important to retrofit programs) and the definition of functionally common SEMs.

Among the quantitative findings, the following appear the most significant:

(1) The life cycle costs of a retrofit application of the APS-129 design would be dominated by the acquisition costs (63% to 68% for the analyses considered).

(2) A retrofit application of the APS-129 design maintenance manpower would represent only a small portion (.5% to 1.9% for the baseline analyses) of the life cycle costs.

The conclusions reached in this study were that:

(1) There exist design alternatives for the APS-129 which could improve the interface of the SEM technology with Air Force maintenance policies and procedures.

(2) That the SEM concept offers positive potential as a life cycle cost and logistics supportability oriented design technology.

INTRODUCTION

General

This report documents a research study conducted to evaluate the potential benefits of the standard electronic module (SEM) design technology for the U. S. Air Force Avionics Laboratory. The approach of the study was to consider the advanced development model of the AN/APS-129 weather-search-navigation radar* as a demonstration vehicle of the SEM concept. Both quantitative and qualitative factors were addressed.

This section will describe the background of the APS-129 development effort and culminate in a statement of the objectives of this study. In the next section, the approach to evaluating the APS-129 and the SEM technology will be described. Following that, the discussion section will focus on the qualitative assessment of the APS-129. The quantitative analysis of APS-129 life cycle costs in a variety of retrofit programs is then presented. Subsequently, findings are stated and results are summarized.

Air Force Avionics and Standardization

There is mutual agreement throughout the Department of Defense and the Defense-related industry that the rising costs of military systems is a major problem. There is also agreement that the increasing sophistication of electronic subsystems and equipments has contributed significantly to this trend. The impact has been felt across the entire spectrum of the life cycle of equipments -- from advanced development to operations and logistical support. One result of this has been the increasing awareness of the life cycle costs of electronics. Typically, sophisticated equipments cost more for initial procurements and require more skillful technicians to maintain them.

The Air Force Avionics Laboratory (AFAL) is the principal development organization within the Air Force Systems Command for new avionics technology. In response to the life cycle cost trends, one of the technical initiatives being pursued by AFAL is the exploration of standardization technologies and concepts.

An extensive amount of literature exists which describe alternative concepts of standardization and the potential benefits. For example, the Electronics-X study[(1)]** addressed standardization with regard to generic reliability and cost factors. Other documents[(2,3)] address other elements of avionics standardization. The general concept of standardization is to buy larger quantities of fewer types of equipment/parts to reduce acquisition costs. An additional benefit to the operations and logistics communities is the potential for reduced levels of:

* Hereafter referred to as the APS-129 radar

** Superscripted numbers in parenthesis refer to the Reference List.

- o support equipments
- o spares
- o maintenance skills and training
- o maintenance manpower
- o technical orders

Thus, the purpose of standardization is to reverse the trends resulting from increased sophistication. However, counter to these potential benefits, there are also some potential risks. These risks concern the problems with technological obsolescence of discrete components and limitations on design flexibility.

Three types of avionics standardization are identifiable:

- o standard equipments
- o standard form, fit, and function (F^3) specifications
- o standard electronic modules

Of these, the first has received the most application in the Air Force. The most recent examples being the ARC-164 UHF Radio Program and ARN-118 TACAN Program[3], which are being procured in large quantities to be used commonly by numerous aircraft. The second type of standardization has been successfully applied by the civilian air transportation industry. The Air Force has experimented with the concept; most notably in the area of inertial navigation systems, as described in Reference 4. The third type of standardization, standard modules, has been applied by the U. S. Navy since 1962. The system studied in this research program represents the first fabrication of an Air Force avionics system using the Navy's SEM concept. However, the Navy's SEM program is more than a design technology. It is also a life cycle management concept involving both quality assurance and design review activities throughout the useful life of a specific, functional SEM. The Navy's technical activity controls the interface design, the quality assurance program and the functional design of standard modules. More details regarding the Navy's SEM program are given in Appendix A.

The three standardization concepts represent attempts to achieve the benefits of standardization in several different ways. They also have differing risks associated with them. The concepts are briefly compared in Table 1 by noting the various categories of benefits and risks. The objective of this report is NOT to decide which concept is best. However, the different concepts are described here to provide a foundation for evaluating the standardization philosophy represented in the APS-129 radar design.

TABLE 1. GENERAL COMPARISON OF AVIONIC STANDARDIZATION CONCEPTS

Type of Standardization	Potential Benefits	Risks
Standard Equipments	• Large Production Runs • Shared Support Resources with Other Weapon Systems	• Standardize on Poor Equipment • Technology Obsolescence of Discrete, Special Parts • Development Costs and Barriers
Standard Specification (Form, Fit, Function)	• Open Market Place • Responsive to New Technology • Internal Design Flexibility (particularly with contractor repair warranties)	• Multiple: - Configurations - Repair Processes - Stock Numbers • High Dollar Value Spares
Standard Modules	• Shared with Other Systems • Discard at Failure • Responsive to New Technology Without System Level Redesign • Open Market	• Size Constraint • Weight Overhead Penalty • Design Flexibility Constraint at Functional Level

The APS-129 Development Program

In the early 1970's, the Naval Electronics Laboratory Center (NELC) initiated a program at the Naval Avionics Facility - Indianapolis (NAFI) to design a family of shipboard surface search radar systems. The primary objective was to achieve inter-system commonality of those functions which could be partitioned into SEM components. This represented an opportunity to expand SEM technology into radar systems. For radar systems, it represented an opportunity to design commonality into multiple applications. Four baseline shipboard configurations were identified by NAFI and NELC.

In the same time frame, the Air Force Logistics Command had recognized a requirement to replace,or make major modifications,to the APN-59 search radar being used in C130, C135, and C141 aircraft. The APN-59 was initially designed in 1950[5] and various alternatives have been evaluated for updating the radar in the various aircraft.[6] The most recently evaluated proposal is a solid state modification of the radar using a one-for-one Line Replaceable Unit (LRU) exchange concept.[7]

In 1974, AFAL joined with NELC to fund the development of search radars in the Modular Radar Program at NAFI. The APN-59/B mission and function was selected as the candidate system for demonstration of the SEM concept in an avionics environment. The Modular Radar Program has since added a sixth design (in addition to four ship types and the airborne) in the form of a tactical weather radar (TWR) for the Air Force's Electronic Systems Division. The interim report on the Modular Radar Program was published in 1975 and describes the NAFI development efforts.[8]

The AFAL portion of the program was initially identified as the Standard Electronic Modular Radar. Recently, the system has been officially designated the AN/APS-129 radar. Two system sets have been fabricated for AFAL and one system is intended for flight testing by the 4950th Test Wing at Wright-Patterson Air Force Base during calendar year 1978.

Description of the APS-129

The APS-129 is an airborne search radar designed for use in cargo/ tanker aircraft. Functionally, it replicates the function of the APN-59/B search radar with the exclusion of the antenna system. Figure 1 shows the various LRU's which compose the APS-129 system. The primary LRU, the receiver transmitter (R/T), is shown in more detail in Figure 2. This figure shows the "open door" design concept for gaining access to the SEMs in the R/T. Figure 3 is a schematic of the conceptual installations in the standard version (two indicators and navigator controllable mode) and the pilot operable version (one indicator and a pilot control box). The differences between this configuration will be noted further in the Discussion Section. Tables 2 and 3 are extracts from NAFI documents which compare the configuration and functional characteristics of the APS-129 with the APN-59.

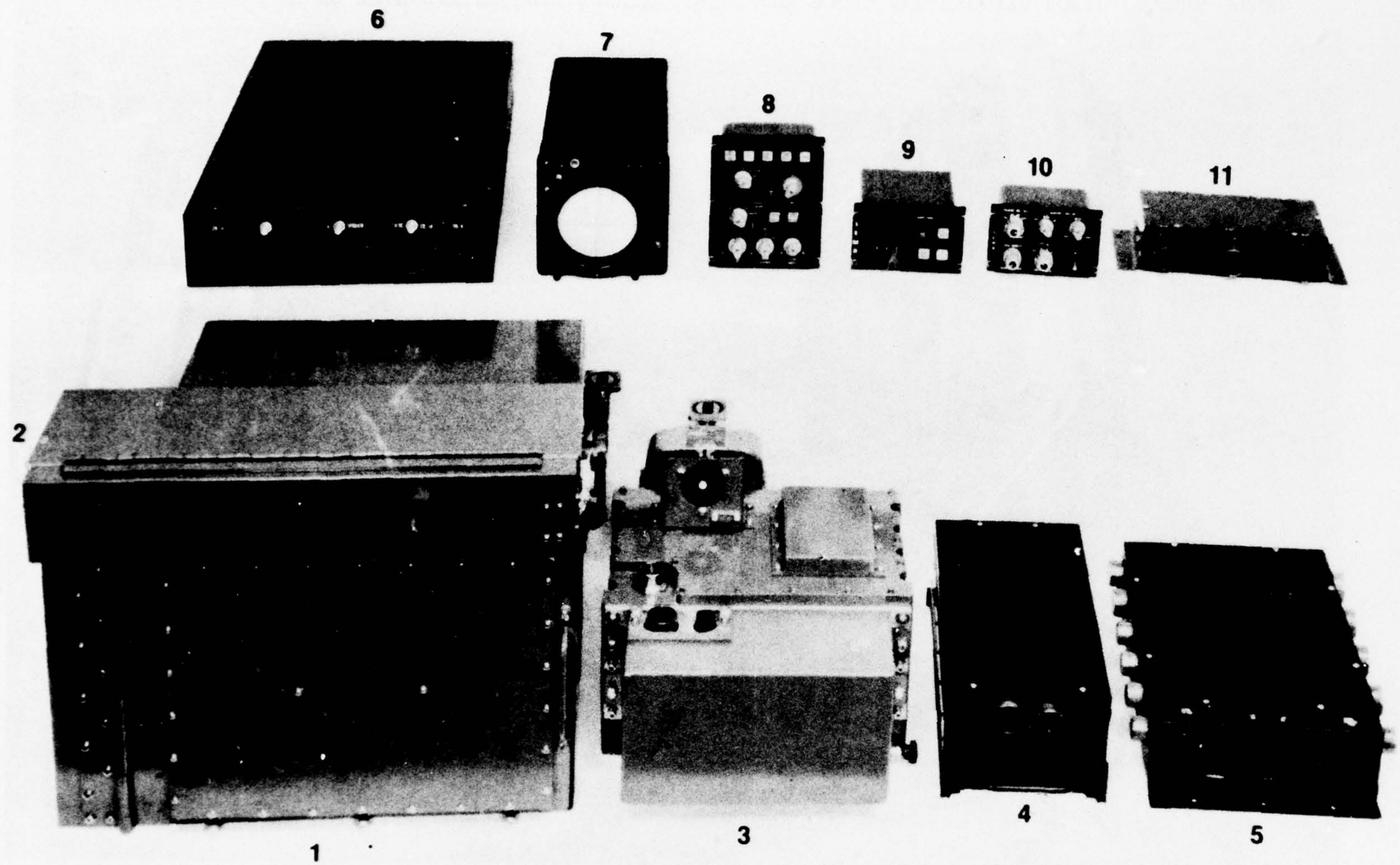


FIGURE 1. COMPONENTS OF THE APS-129 RADAR SYSTEM

LEGEND:

1.	Receiver-Transmitter	4.	Antenna Control Electronics	7.	Indicator	10.	Display Control
2.	Local Control	5.	Junction Box #8	8.	Radar Control Unit	11.	Junction Box #9
3.	Modulator Unit	6.	Display Electronics Unit	9.	Remote BITE Unit		

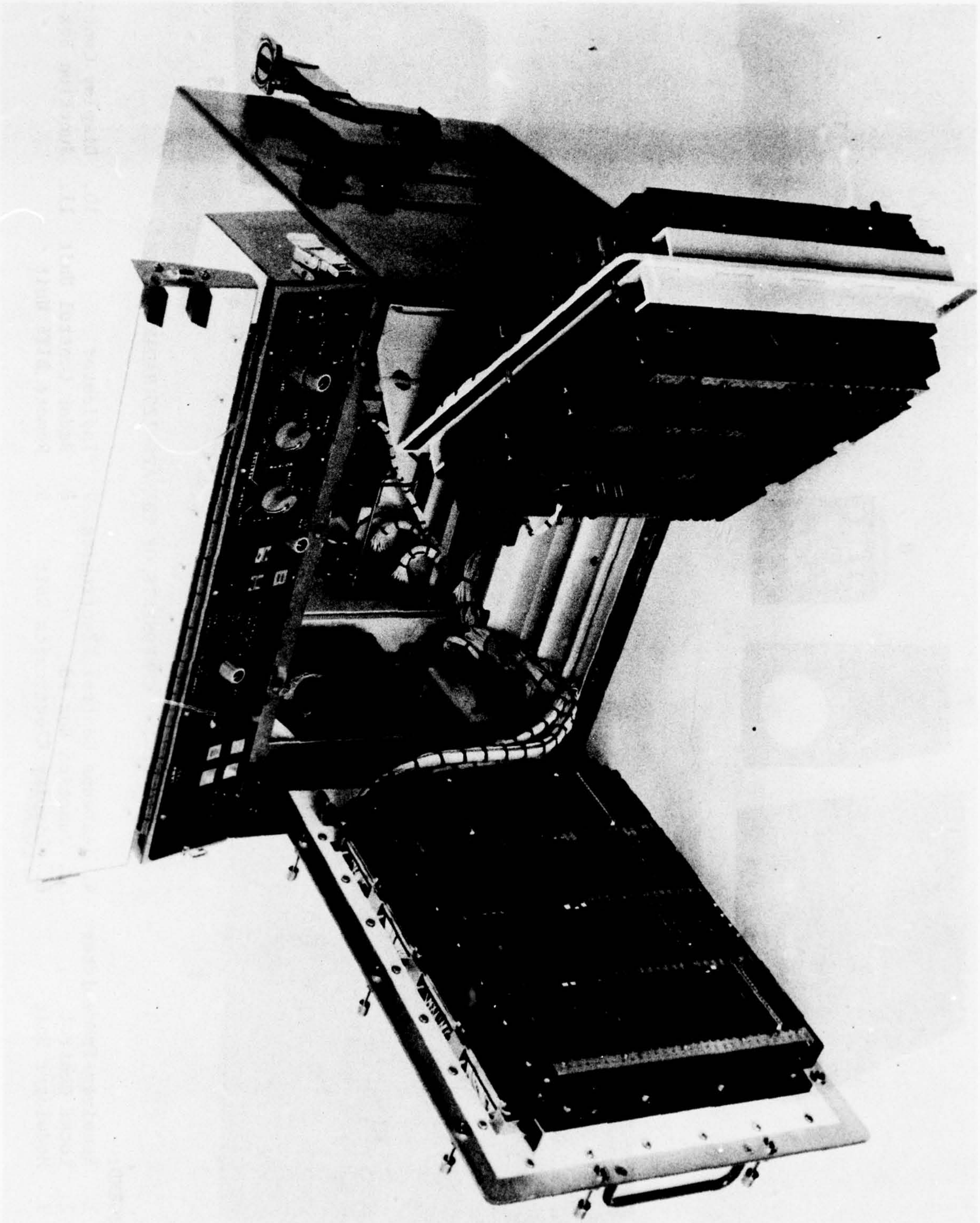


FIGURE 2. RECEIVER-TRANSMITTER UNIT SHOWING SWING OUT DOORS AND EXPOSED LOCAL CONTROL PANEL

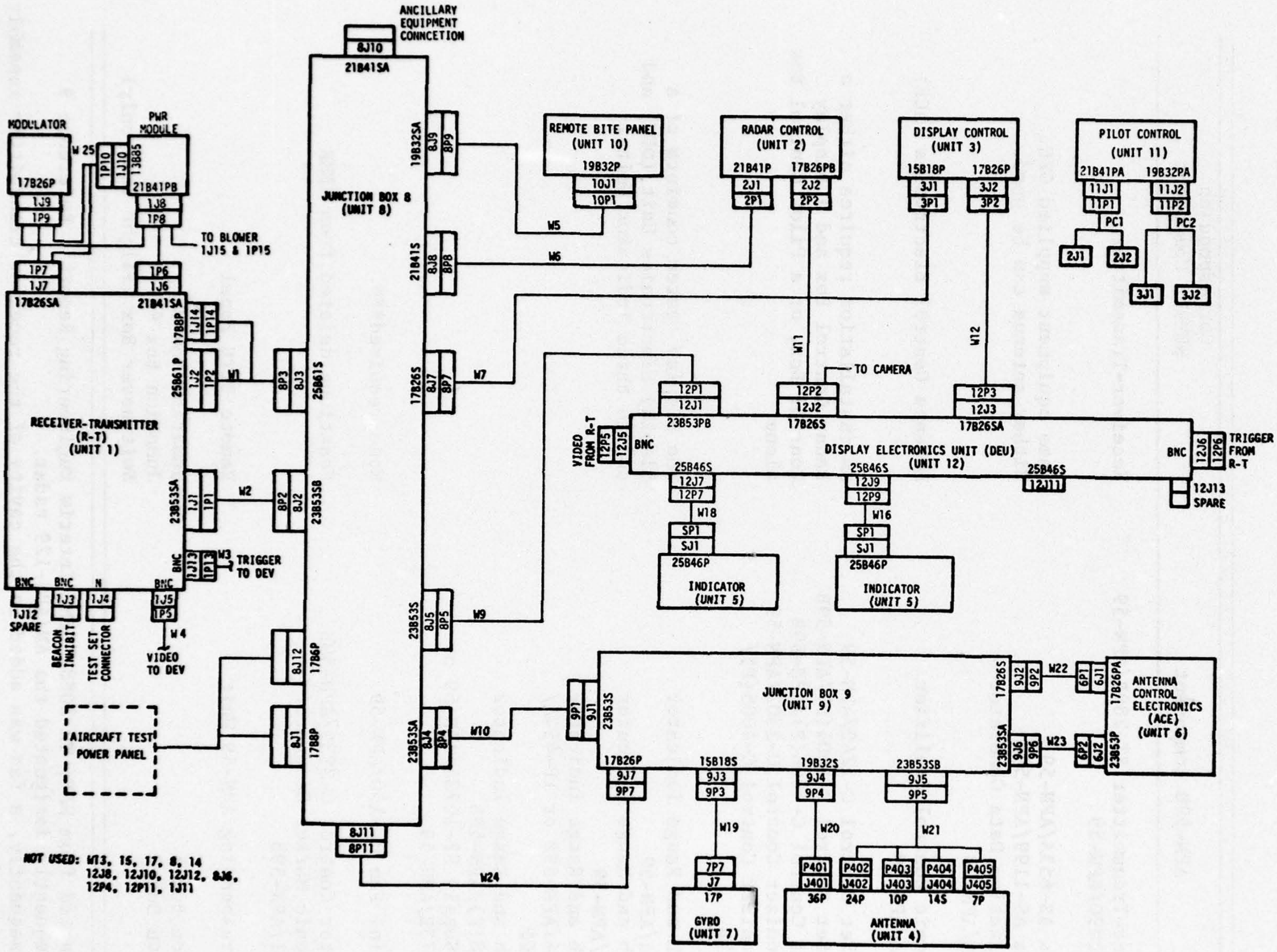


FIGURE 3. RADAR SET AN/APS-129 (SEMR) CABLE DIAGRAM

TABLE 2. SYSTEM COMPONENT COMPARISON*

APN-59B Component	Corresponding SEMR** Component
Receiver-Transmitter RT-289B/APN-59 or RT-289C/APN-59	Receiver-Transmitter
Antenna AS-653A/APN-59 Antenna AS-1199/APN-59B Stabilization Data Generator CN-221A/APN-59	Same equipment supplied GFE. Either antenna can be used.
Electronic Control Amplifier AM-853A/APN-59	Antenna Control Electronics (ACE)
Radar Set Control C-1242/APN-59 Radar Set Control C-4004(P)/APN-59B Antenna Control C-4006(P)/APN-59B Synchronizer Control C-2302/APN-59 Synchronizer Control C-4005(P)/APN-59B	An installation requires either a Radar Control Box and a Display Control Box, or a Pilot Control Box alone.
Azimuth and Range Indicator IP-239A/APN-59 Azimuth and Range Indicator IP-268/APN-59 Azimuth and Range Indicator IP-454/APN-59B or IP-454A/APN-58P Azimuth and Range Indicator IP-628(P)/APN-59B Power Supply PP-1073A/APN-59 or PP-1073B/APN-59	The display system consists of a Display Electronics Unit (DEU) and one to three Indicator Units.
Vaneaxial Fan HD-150/APN-59	None required***
Generator Control C-3939/APN-59B Electronic Marker Generator SG-461/APN-59B	Functions deleted from SEMR
No corresponding APN-59 Unit	Remote BITE Panel
Junction Box 1 Junction Box 2	Junction Box 8 Junction Box 9 Switchover Box (Flight test only)

* Extracted from NAFI TR 2088,"SEMR Interim Engineering Report", Reference 9
**Subsequently designated the AN/APS-129 radar.
***Subsequently, a fan was added in the cavity of the receiver transmitter assembly.

TABLE 3. BASIC RADAR PARAMETERS COMPARISON*

Item	Radar	AN/APN-59B	SEMR
1	POWER	70kW NOM, 50kW MIN	70kW NOM, 50kW MIN
2	TRANSMIT FREQUENCY	9375 ± 40 MHz	9375 ± 20 MHz
3	NOISE FIGURE (db)	14	10 MAX
4	PULSE WIDTH (μs)	4.5, 2.35, .8, .35	4.0, 2.35, 0.4
5	PRF (PPS)	2000, 1025, 350, 130	2000, 1000, 250
6	RECEIVER IF FREQUENCY	30MHz	60 MHz
7	IF BANDWIDTH (MHz)	6 for .35 & .8μs, .75 for 4.5 μs	4.0 for 0.4 & 2.35 μs 0.5 for 4.0 μs
8	ANTENNA	FAN & PENCIL BEAM	FAN & PENCIL BEAM
9	ANTENNA GAIN (db)	28.5 PENCIL 25.5 FAN	28.5 PENCIL 25.5 FAN
10	BEAM WIDTH	FAN AZ 3°, EL 40° PENCIL AZ 3°, EL 5°	FAN AZ 3°, EL 40° PENCIL AZ 3°, EL 5°
11	SCAN RATE (RPM)	11-16 for Sector, PPI 100, 240 42-56 for PPI 3-30, 50	11-16 for Sector, PPI 120, 240 42-56 for PPI 3-30, 60
12	ANTENNA STABILIZATION	-12° to + 15° pitch 30° roll	-12° to + 15° pitch 30° roll
13	DISPLAY RANGE (n.mi)	3-30 50, 100, 240	3-30, 60, 120, 240
14	DISPLAY MARKERS(n.mi.)	1-5 in 3-30 10 for 50 20 for 100 30 for 240	1 for 3-11, 5 for 11-30 10 for 60 20 for 120 40 for 240
15	MODULATOR	MAGNETIC	SOLID-STATE MAGNETIC
16	APPLICATION	AIRBORNE WEATHER & NAV (BEACON)	AIRBORNE WEATHER & NAV (BEACON)
17	ENVIRONEMENTAL SPECIFICATION	MIL-E-5400 Class 1	MIL-E-5400 Class 1

*Extracted from NAFI document, "Comparison of SEMR with Radar Set APN-59/B", Reference 10.

Research Objectives

Several efforts to quantify the impact of standard modules upon avionics have been made by various members of the electronic community.* With the exception of the work by Huss at NAFI,[11] these have not been associated with actual hardware fabrication efforts. As noted earlier, the APS-129 is the first Air Force avionics system to be designed and fabricated using SEM technology. Given this opportunity, this research project was initiated to obtain a thorough and objective analysis of the APS-129 design and investigate the implications of the SEM concept upon the life cycle costs of avionic systems.

Specifically, the research objectives were to:

(1) Quantify the life cycle costs of the APS-129 design as if it were to be employed in a retrofit application.

(2) Assess the logistics impact of discard at failure maintenance, built in test confidence level, and alternative maintenance concepts.

(3) Evaluate the life cycle cost impact of alternative design concepts.

The next section will describe the approach to satisfy these objectives.

* See References 11, 12, 13, 14, 15, 16

APPROACH

General

In this section, the specific factors which were considered in evaluating the APS-129 design and life cycle costs of a retrofit program are identified. The procedures used in collecting information for these factors and structuring the analysis are also noted.

Evaluation Factors

As noted earlier, the standard module program (SEMP) at NAFI has evolved into both a design technology and a logistics management concept. Therefore, factors addressing both of these areas were identified, reviewed and evaluated. The general potential for using the SEMP technology was also considered a distinct evaluation area. For some of the factors, the evaluation was accomplished considering two levels of information: (1) factors related to the SEMP in general, and (2) factors related to the specific APS-129 design. The applicability of these factors is shown in Table 4. The order of the factors is indicative of the increasing potential for quantification of the factor for evaluation (i.e. technology obsolescence is rather difficult to quantify while life cycle costs will be quantified in detail).

Information Collection

The initial efforts to collect information for this study focused on the SEMP in general. For this information, contact was made with Mr. Ron Huss, NAFI; Mr. Larry Milligan, Defense Electronics Supply Center (DESC), Dayton, Ohio; and Mr. John Wyatt, Naval Electronic Systems Command, Washington, D.C. Through this process, several reference documents were obtained.*

Next, information relative to the specific APS-129 design was obtained from NAFI; via direct contact with NAFI or through AFAL. This included many detailed drawings and documents (far too many to identify specifically). Most notable of these documents were the monthly Research and Development Status Reports submitted to AFAL by NAFI**, the documents comparing the APS-129 with the APN-59[10,36] and a paper describing the built-in test concept of the APS-129.[37] In addition, the APS-129 reliability analysis performed by the Rome Air Development Center for AFAL[38] was made available through AFAL.

Data regarding the hypothetical retrofit programs were obtained from Air Force Logistics Command (AFLC) personnel at AFLC Headquarters, Wright-Patterson AFB, Ohio and Warner Robins Air Logistics Center, Georgia. (Warner Robins ALC has item management responsibility for the APN-59/B radar and system management responsibility for the C 130 and C 141 aircraft).

* References 8, 15 and 17 through 28.

** References 9 and 29 through 35.

TABLE 4. EVALUATION FACTORS AND APPROACH

EVALUATION FACTOR	EVALUATION AREA		LEVEL OF IMPACT		
	Design Technology	Logistics Concept	Candidate For Retrofit	SEMP	APS-129 Design
Technology Obsolescence	X	X	X	X	
Design Review Process	X			X	
SEM Procurement Concept	X	X		X	
Commonality	X	X	X	X	X
Weight and Volume	X		X		X
LRU Format	X	X	X		X
BITE Concept	X	X			X
Maintainability	X	X			X
Reliability	X	X			X
Life Cycle Cost	X	X	X		X

Concurrent with the other data and information channels, a document search was exercised through the Defense Documentation Center information system. Documents obtained through this channel included references 3, 6, 11 and 16.

Analysis Activities

Formulation of the evaluation factors and collection of information and data led to the following reviews and analyses:

(1) A review of the APS-129 design philosophy

(2) An independent reliability analysis

(3) An independent cost analysis

(4) A logistic support cost analysis

(5) A sensitivity analysis of the aggregated life cycle costs to evaluate potential design changes.

In some instances, the information used in these analyses represent the interpretation of available information and "best estimates" by members of the research team. The sensitivity analysis represents an effort to study the impact of these estimates upon the analytical results.

DISCUSSION

General

This section presents a qualitative discussion of selected evaluation factors noted in the previous section. It does so by relating the factors to the SEMP concept, and to the characteristics of the program as demonstrated by the APS-129 design. Where appropriate, specific APS-129 design features are discussed. A separate sub-section will address each of the first ten factors listed in Table 4. A general review of the APS-129 design philosophy will conclude this section. The life cycle cost analysis will be presented in the next section.

Technology Obsolescence

One of the basic principles of the SEMP approach is that the modules are functionally specified rather than piece part specified. This has advantages in all three evaluation areas when considering the rate of change in electronic technology. For example, the designer has flexibility to alter the specific circuitry of an approved SEM in order to:

(1) Take advantage of new technology

(2) Design out technology for which piece parts are no longer available

(3) Become more price competitive

Acceptance of these concepts in SEMP was noted in a 1971 document[33] during the state-of-the-art transition from diode-transistor logic (DTL) to transistor-transistor logic (TTL). Subsequently LSI and C-MOS circuitry have arrived on the scene.

This flexibility represents mixed benefits in the logistics area. Logisticians are usually very concerned about configuration control; particularly when maintenance documentation must be continually updated. In the case of the SEMP, however, the discard-at-failure-maintenance (DAFM) concept of the SEMs resolves this level of concern. Moreover, the allowed flexibility of the designer offers the potential for accepting new technology in the next higher level of assembly without changing that level or the rest of the system. Modification of special circuitry can become very expensive when a specific electronic component is the heart of a function and is no longer manufactured for the commercial market. The usual alternatives are to pay abnormally high costs (and be dependent upon a sole supplier) or fund a redesign effort. This phenomenon is arising with more frequency in the logistics engineering community.

This technical flexibility of the SEMP approach is also considered to have positive implications for using SEMP in retrofit programs. The retrofit programs being pursued in recent years have typically been aimed at replacing old, vacuum tube technology in the scenario just described above.[3] It is intuitive that a primary concern of management in these instances should be to not replace one obsolete technology with another technology which has an even shorter life expectancy. In this area, the SEMP has an advantage over the "standard equipment" type of standardization.

The APS-129 design does not fully capitalize on this factor because of the high level of non-SEM circuitry. As will be shown, SEMs represent only 46 to 49% of the system failure rate. Thus, over half of the system failure rate may be attributable to components which are subject to technological and/or economic obsolescence.

The design review process which NAFI performs for the SEMP may, on the whole, have a negative impact upon the design of a new system. Currently, each new proposed SEM standard must be submitted for a review prior to its acceptance. By placing an external, uncontrollable (by the contractor's manager and lead engineer) loop in the detail design phase, this has the potential for causing delays in the prime contractor's design effort. Design changes do occur throughout a development process and when these occur after a proposed standard module has been submitted, duplication of effort and costs may occur.

During development of new designs or sources of specific SEMs, the design review process makes a significant contribution in assuring "function" compatibility. However, even here, the time delay and anticipated vendor cost (approximately $30,000[20]) may form an economic barrier to qualification.

SEM Procurement Concept

The procurement of economic quantities of SEM's appears practical only during the acquisition phase of the system. For reprocurements, the Navy organizations have not established a central-procurement activity. It is understood that the Defense Electronics Supply Center has, in its new role as tri-service focal point for the SEM program, considered the feasibility of stocking the qualified SEM's in special federal stock classes. Until such a management role is assumed by some organization, it appears that maximum procurement leverage will not be exercised.

Commonality

The basic premise of standardization - larger quantity procurements at lower average costs - may be achieved by the SEMP in two dimensions. The first is intra-system; where specific modules may be used in multiples and in more than one sub-assembly. The second dimension is inter-system; where the same module may be used in other systems intended for similar or different missions. This feature of the SEMP is considered to be a slight disadvantage

in the design of totally new systems when entirely new functional modules have to be developed. Conversely, this may have considerable impact in the areas of logistics supportability and retrofit potential. Use in other systems may provide a continuous production requirement. Also, supply excesses which occur at the phase-out of one system may be utilized by other systems.

Emphasis on this facet of the SEMP may cause suboptimal decisions in the design of a specific system. It is very unlikely that a system could be designed entirely from existing standard modules. The functions not covered may be subject to "commonality" without considering the potential return on the investment by using it in many other systems. The current NAFI definition of commonality is sharing a SEM by two or more systems. The investment, by manufacturers, in qualification costs and quality assurance procedures may not be warranted at such a low "commonality" threshold.

When the modules are shared across systems, and in multiples within the system, the impact upon supply levels is very advantageous. This will be noted later in the life cycle cost analysis.

In the area of retrofit programs, the incorporation of modules previously introduced and operating in the "real world" mission environment is considered to reduce the technical risk of the program as well as the costs.

If considered by itself, the APS-129 design would not benefit much from commonality. Table 5 compares the proportion of SEMs shared by the APS-129 and other SEM systems. The data on the other systems was extracted from Reference 16. The APS-129 has only 22 existing standard types (23%). However, the APS-129 was developed under the auspices of the Modular Radar Program. The figures in Table 6 reflect quite a different situation. If all of the MRP systems were to proceed, 59 of the 95 module types (62%) would be shared by more than one system. This is considered to be an effective level of inter system commonality.

Weight and Volume Overhead

This characteristic of SEMs has probably received the most attention by reviewers of the concept. Weight and volume penalties are associated with SEM's[16] because the card cages and circuit board interface hardware. However, as emphasis on life cycle costs increases, this should be subject to more favorable treatment in trade-off analyses.

The APS-129 program is, in general, a good example of this. One of the aircraft systems currently using the APN-59/B radar is the C141. Studies have indicated that, in service as a transport, the C141 is more often volume limited than weight limited.[40] Such studies are the basis for the current prototyping of a "stretch" version of the C141 which will add weight and volume to the basic airframe. Another recent example of cost-weight trades at the system level is the A-10 airframe/GE T34 engine "design-to-cost" experiences[41] where performance was traded for improved producibility. The impact of these examples is that weight increases do not receive the automatic rejection stamps that was traditional a few years ago.

TABLE 5. MODULE COMMONALITY ACHIEVEMENTS*.

System	Total: A Module Types	Total: B Modules/ System	Existing Stds: C Types	Existing Stds: D Modules/ System	Ratios: B/A Total Modules Per Type	Ratios: D/C STD Modules Per Type	Ratios: C/A STD PCT. Types	Ratios: D/B STD PCT. Modules
TRIDENT FCS	145	15,334	107	7,690	105	72	.74	.50
TRIDENT Sonar (BQQ-6)	114	14,840	92	7,199	130	78	.81	.48
SAMAC	55	758	44	677	13.8	15	.8	.89
MK 116 MOD 1 FCS	30	731	18	517	24.4	29	.6	.70
MER/TER Test Set	26	76	12	32	2.9	2.6	.46	.42
APS-129*	95	348	22	150	3.7	6.8	.23	.43

*Area enclosed by dotted line is information extracted from: "Electronics Standardization in the Navy", Reference 16.

TABLE 6. APS-129 COMMONALITY WITH OTHER MODULAR RADAR PROGRAM DESIGNS

Module Status	Types	Qty.
Standards	22	150
New Development	73	198
Shared with Modular Radar Program	(37)	(148)
Unique to APS-129 Design	(36)	(50)
Total	95	348

Table 7 presents the weight and volume data on the APS-129 system. The weight represents a 84% increase over the nominal APN-59/B configuration. However, it must be remembered that the design is an advanced development model. Among other things, the oil-filled modulator would probably be replaced with a lighter element if development continued.

LRU Configuration

The segmentation of an avionics system into Line Replaceable Units (LRU) is influenced by the design technology. For SEM applications, the grouping of system functions into LRU compatible subfunctions affects the potential for partitioning electronic functions into SEMs. However, partitioning the system into LRU's also has implications upon retrofit feasibility. An LRU partition which yields a different form-fit-function interface with the existing hardware causes the addition of modification costs to the program. In such a case, the investment which a retrofit program must be able to recover, through reduced out-year support costs, is increased.

A brief discussion of the economics of the LRU exchangeability issue will illustrate the magnitude of the problem for retrofit programs. In recent years, the Air Force Logistics Command has considered several courses of action aimed at reducing the support costs on the APN-59/B. One alternative was the replacement of the system with the APQ-122V radar system which was developed under contract by the Air Force Systems Command. A second alternative was the replacement of the APN-59/B with commercially developed airborne weather radars. The third approach involved selective modification of the existing APN-59/B design and replacement of some of the original LRU's with modified units. Neither of the first two alternatives involved LRU exchange. Reference 6 documents the AFLC economic analysis of the APQ-122V program. In that document, one time costs of $2.7 million (1972 dollars) were included for installation kits and labor. During the course of this project, estimates were obtained from Warner Robins Air Logistics Center personnel for installation costs of commercial radars in the C141 aircraft. The Warner Robins personnel estimated that mounting fixtures (Class A kits) would cost $6,000 - $7,000 per aircraft set and the modification would require approximately 350 direct labor hours per aircraft. For a fleet of 276 aircraft, and using a typical AFLC standard of $20.00 per depot level labor hour, the incremental cost of these installations can be estimated to be $3.7 million. Comparable factors for installation of non-LRU exchangeable avionics in C 130 aircraft are documented in reference 2. These sums may become significant when evaluating the potential for recoupment of initial investments.

According to the Third NAFI R&D report to AFAL,[31] design alternatives considered for the APS-129 included an LRU exchangeable concept. With AFAL approval, however, a non-LRU exchangeable format evolved. The statement of work under which this life cycle cost study was accomplished directed that the analysis be based on the existing design. Therefore, the life cycle cost estimates include installation costs which would be required because of the non-LRU exchangeable design.

TABLE 7. APS-129 COMPONENT DIMENSIONS AND WEIGHTS

Component	Dimensions[1] in Inches			Approx. Weight In Pounds
	Height	Width	Depth	
Antenna AS-653A[2]	34-1/4	--	35-3/4 dia.	55
Stabilization Data Generator[2]	7	--	8 dia	8
Receiver-Transmitter (overall)[3]	18	34-13/16	18	203
Local Control Panel	4	21-1/2	7	Included in Main Cabinet
Main Cabinet	14	21-1/2	18	110
Modulator/Power Converter	11-3/8	15	18	88[4]
Mounting Plate	3/4	32-3/4	14-1/2	5
Antenna Control Electronics (ACE)	5	7-1/4	13-5/8	14
Indicator	6-1/2	6-1/2	15	10-1/2
Display Electronics Unit (DEU)	4	17-7/8	25	53
Display Control Box	3-3/4	5-3/4	3-1/4	1-3/4
Radar Control Box	7-1/4	5-3/4	3-1/2	3-1/4
Remote BITE Panel	3-3/4	5-3/4	5	2-1/2
Pilot Control Box	7-7/8	5-3/4	3-1/2	3
Junction Box 8	14	10	3-1/2	4-1/2
Junction Box 9	9-1/2	5	3-1/2	2-3/4

[1]Connectors not included.

[2]AN/APN-59B Components. Data from T.O. 12P5-2APN59-22.

[3]The Receiver-Transmitter (R/T) Unit is itemized in parts and also as a complete unit

[4]Includes 15 pounds of liquid coolant.

Built In Test Equipment (BITE) Concept

In avionics, BITE can serve two roles: (1) as a malfunction indicator for the operator or (2) as a maintenance tool. In designing the BITE, it is necessary to clearly define which role it will be assigned. With the application known, the designer can determine the level of sophistication that is needed and therefore the design approach which should be used.

The BITE level of sophistication is controlled by the level of indenture to which the failure must be identified. In the role of malfunction indicator, the BITE needs to identify the system, or function, which has failed or is operating in a degraded mode. Additional useful information would be identification of the major subsystem (LRU) which has the problem. For this level of sophistication, it is envisioned that the BITE can be developed from signal flow diagrams, since the interconnects are relatively few in number.

If the BITE is to be used as a maintenance tool, the level of sophistication required is increased. To be an effective tool, the fault should be identified to the failed item at the lowest level of indenture to be replaced on-equipment (e.g. board, module, LRU). To do less would: (1) require duplication of test equipment capability at a higher level of repair (intermediate or depot); or (2) cause iterative replacement of a number of items (including good ones) until the system is returned to operable condition. The approach used in developing the BITE for this application should include a failure mode and effects analysis. Such an analysis would assure that all fault paths are identified.

Other concerns with BITE concepts involve the physical location of the BITE, whether it is an active or passive BITE, and whether or not a BITE failure constitutes a system failure. In the APS-129 design, each receiver/transmitter unit includes an active BITE subsystem. Because a failure of the BITE would require a maintenance action, the BITE subsystem failure rate was included in the system failure rate. The BITE identifies failures to groups of 3 to 8 modules and, therefore, does not accomplish full fault isolation. However, a design alternative evaluated by the research team postulated that the number of SEM's in each R/T could be reduced (also acquisition costs and system failure rates) if the BITE system became part of a intermediate shop hot-mock-up. The analysis of this alternative is presented after the baseline analyses.

Maintenance Concept

The APS-129 Radar was designed for on-equipment maintenance in a manner similar to the maintenance of shipboard systems. As noted in Figure 2, the SEM's in the R/T cabinet are accessible on swing-out doors. The SEM's in the display electronics and antenna control electronics units are accessible after removal of one panel (on each unit). This concept, however, in the judgement of the research team, does not appear appropriate for this radar system for two reasons. First, the location of the APS-129 in the avionics bay would not be conducive to SEM level fault isolation and replacement. Secondly, such a maintenance concept would require that an entire set of SEM's be available to each flight line repair technician. Since the SEM's are envisioned to be

expendable items, current maintenance and supply procedures would prohibit the return of unused SEM's to supply. Thus, there would exist the potential for excessive utilization SEM's. This concern is also impacted by the BITE concept, alluded to earlier, which results in iterative replacement of a small group (3 to 8) of SEM's until the system is operable.

Because of these concerns, the baseline life cycle cost analysis was performed on the basis of major black box (i.e. items in Figure 1) removal and SEM and subassembly fault isolation at the intermediate maintenance level.

Maintainability Overview

If the definition of the term maintainability is limited to "the ease of repair given that the proper supplies are available and adequate work conditions exist", then the research team would evaluate the maintainability of the SEMR design as being more than adequate. The components are accessible and the BITE appears to be easily interrogated. However, because of the location of the equipment in the aircraft; the supply procedures for expendable items, and the degree of BITE, it was the team's finding that the interface of the radar with the Air Force Avionics maintenance environment could be improved. As a result, a design alternative was hypothesized which restructured the R/T cabinet into several, smaller LRU's. The analysis of this alternative is presented after the baseline analysis.

Reliability

The reliability of SEM's is established, and maintained, by NAFI assuming control of the factors which effect reliability. The factors which are controlled are: (1) qualified components and connectors, (2) power dissipation and electrical ratings, (3) quality control and assurance in assembly and (4) evaluation through a test qualification program. Thus, the reliability of each "qualified" SEM is maintained as high as possible. However, reliability of a system consisting of SEM's is dependent on observing the collective interactions so that the overall reliability is not degraded by combined heat generation on electrical load ratings.

One of these interactions did occur in the APS-129 program. During predelivery testing, heat problems arose because of the design of the APS-129 receiver-transmitter (R/T) cabinet. Therefore, the reliability analysis was conducted using an 80° C temperature. The design alternative conceptualized to improve the maintenance interface of the R/T cabinet may also reduce the heat generation problem by allowing greater exposure to ambient air.

When discussing the reliability of discrete SEM's, it is important to maintain an awareness of the non-SEM portion of the system. That portion is not generally subjected to the continuous reliability control of SEM's. Therefore, if the percentage of the system which is not SEM is large, investment in the reliability of qualified SEM's may not be efficient.

ANALYSIS

This section presents the results of the quantitative analysis conducted on the APS-129 design. The preliminary estimating processes and results will be described. Then, the LCC model will be described and the assumptions used in exercising the model will be stated. Following a discussion of the baseline results, results of sensitivity testing, and two design alternatives are analyzed.

Component Reliability and Cost Estimation

The reliability analysis of the APS-129 design was performed on the SEM's and discrete components. For qualified standard SEM's, the published failure rate was used. For SEM's listed as under development, or not qualified, and discrete components, Mil Handbook 217B(42) was used to establish a failure rate. In applying 217B procedures, all components were assumed to be Mil Std parts as would be required for a final system configuration. The environment conditions selected were airborne inhabited with a maximum environmental temperature of 80°C. This temperature was deemed justified on the basis of the heat problems discussed previously. Where operating parameter data were not available, it was assumed the components were stressed at a maximum of only 50% of their electrical rating.

Initial cost estimates for qualified SEM's were established by evaluating the following sources: (1) *The Air Force Study of a* Module Digital Scan Converter,(43) (2) Module Commonality between 2175 Modular Radar and the Tactical Weather Radar Systems, and (3) Raytheon Price List.(44) Then, non-qualified SEM's were compared to qualified SEM's with respect to components and function performed. Using this comparison and expected component costs and estimated manufacturing costs, a purchase price was estimated for the non-qualified SEM's. All component cost estimates were based on the average cost of the 1000th unit.

Cost estimates for non-SEM portions of the radar were developed by analogy to other radar and avionics systems. Of particular value was the cost data on the APQ-122V(5) radar obtained from the Air Force Aeronautical Systems Divisions program office for the APQ 122 (ASD/AEA).(45) The APQ-122 has many similarities to the APS-129, including the use of an oil-filled modulator.

The results of the above reliability and cost estimating processes are presented in Table 8 and 9. Table 8 also shows the distribution of each SEM type in each of the sections in the APS-129 design.

System Reliability Estimates

The system reliability estimates were aggregated using the work breakdown structure (WBS) in Figure 4. The estimates are tabulated in Table 10. The estimated MTBF's at level 1 and of level 2 components were adjusted to reflect the probability of false pulls. The design goal was a 5% false pull rate. This rate was applied to the first and second level MTBF's to effectively adjust for the increased demands for maintenance and supply actions at these levels. In the tables which follow, both the reference system MTBF and "effective MTBF"

TABLE 8. DISTRIBUTION, RELIABILITY AND COST ESTIMATES OF SEMs

		Location and Quantity											
		Receiver–Transmitter											
Key Code	Module Name	1,1 Receiver	1,2 Timing and Control	1,3 Bite	1,4 System Power Supply	1,5 Modulator Power Supply	3,1 Antenna Control Electronics	4,1 Display Electronic Unit	Estimated MTBF hours $\times 10^6$	Estimated Cost	Size	Status(1)	Shared with Other MRP Systems
TPT	Power Supply				1			1	0.04	350	2G	ND	Type 1-C(2), TWR(2)
UET	Mixer Terminator Module			1					2.15	100	1B	ND	Type 1-C(1), TWR(1)
UFS	D/A Converter		2						0.04	125	1A	ND	Type 1-C(2), TWR(2)
UFZ	Filter, IF	1							0.16	250	2B	ND	
UGW	Timer		2				2		0.4	135	1A	ND	
UMU	Light-Emitting Diode Display		2					2	0.23	100	1A	SP	Type 1-C(2), Type III(3), TWR(1)
U2X	P-Prom							2	4.27	100	1A	ND	
VBS	Modulator/Demodulator	1							0.047	150	1B	ND	
VEW	Sweep Generator							2	0.194	115	1A	ND	
VFT	Integrator/Filter	1							0.135	130	1A	ND	
VHU	Active Filter						1		0.75	210	1B	ND	
VJX	Catch all Mod 4							1	3.23	135	1A	ND	
VLY	Catch all Mod 5							1	0.21	125	1A	ND	
WET	Unblank Driver							1	0.45	75	1A	ND	
WHW	Current Limiter							1	0.03	115	1A	ND	
WHV	AFC/AMP Disc	1							0.03	300	2B	MOD	
WKX	Diode Res Mod	1		1					0.33	125	1A	ND	
WRU	Relay Module						1		0.26	180	1B	ND	
WSY	Switchdriver Trans Mod						2		0.636	125	1B	ND	
WXZ	Signal Condition/Mod						1		0.161	180	1B	ND	
XEV	Capacitors		1						0.2	120	1A	ND	
XFW	Unblank Generator							1	1.94	120	1A	ND	
XJX	Signal Condition/Mod						1		0.677	125	1A	ND	
XKY	Signal Condition/Mod						1		0.55	105			
XPU	Power Converter							1	0.04	350	2G	ND	
XYS	Random Access Memory			2					0.02	100	1A	MOD	Type 1-C(10), TWR(6), Type IV(1)
YBX									1.07	110			
YBZ	Tri-State Buffer		2	6					0.576	45	1A	STD	
YET									0.326	125			
YEW	Video Driver							1	0.686	175	1A	ND	
YPZ	28V Series Reg						1		0.04	125	1D	ND	
YSS	Scott-Tee Transformer							2	1.0	250	1C	ND	
ZBW	Multiplying D/A							2	1.12	125	1A	ND	
–	Memory, Read only							1	0.0028	115	1A	ND	
–	Analog Multiplier							1	0.0219	115	1A	ND	

(1) Status: STD–Standard; IP–In process of becoming standard; ND–New development for modular radar; SP– Special development for another program with no plans to qualify; MOD– Modification of existing module.

TABLE 8. DISTRIBUTION, RELIABILITY AND COST ESTIMATES OF SEMs (Continued)

Key Code	Module Name	Location and Quantity: Receiver–Transmitter: 1,1 Receiver	1,2 Timing and Control	1,3 Bite	1,4 System Power Supply	1,5 Modulator Power Supply	3,1 Antenna Control Electronics	4,1 Display Electronic Unit	Estimated MTBF hours $\times 10^6$	Estimated Cost	Size	Status[(1)]	Shared with Other MRP Systems
FKP	STE Function Control	1							0.5	150	1A	ND	Type 1-C(1), Type III(1), Type IV(1), TWR(1)
GAE	Triple Switch		1			2	2		0.91	125	1B	ND	Type 1-C(1), Type IV(2), TWR(1)
GAF	Regulator	1			1			1	0.84	200	1C	ND	Type 1-C(1), Type III(1), Type IV(1), TWR(1)
GBD	FTC or Video Select Switch	3							0.27	125	1A	ND	Type 1-C(4), Type III(1), Type IV(2), TWR(1)
GDJ	Latch			3			1	6	0.56	80	1A	STD	Type 1-C(3), Type III(2), Type IV(4), TWR(2)
GDM	Counter, Up/Down Binary							2	0.532	150	1A	STD	Type 1-C(1)
GDN	Decoder, Binary			1					1.25	45.5	1A	STD	TWR(1)
GEE	Comparator, Analog							2	1.08	105	1A	STD	
GVQ	Oscillator, Crystal		1					1	3.56	50	1A	STD	Type 1-C(2), Type III(1), Type IV(1), TWR(1)
GZB	Octo-Decimo Buffer, Noninsert			2					0.546	100	1A	ND	Type 1-C(4), Type III(1), TWR(2)
HRH	Microprocessor			1					0.5	300	1A	MOD	
JDB	Comparator, Magnitude							4	0.91	53.67	1A	STD	Type 1-C(1)
KDE	Amplifier, IF	1							0.026	300	2B	ND	
KDQ	Multiplexer, Digital		1				1	5	2.04	60	1A	STD	
KDR	Flip-Flop D-Type		3	2			1		5.26	30	1A	STD	Type 1-C(5), Type IV(4), TWR(3)
KLQ	Rectifier/Filter				1			1	0.23	175	1G	ND	Type 1-C(1), Type IV(1), TWR(1)
LDN	Gate, NAND		1						4.55	35.28	1A	STD	Type 1-C(5), Type III(1)
LDQ	Gate, NAND						5	10	5.56	32.90	1A	STD	
MUM	Isolator, Optical		5	8			3	6	0.32	95	1A	STD	Type 1-C(6), Type III(1), TWR(8)
NQD	Quad 4 Input Analog Multiplexer	2		3	2	4	1	5	0.14	125	1A	ND	Type 1-C(3), Type III(3), Type IV(2), TWR(3)
PFB	Rectifier Filter				3			8	0.128	175	1C	ND	Type 1-C(3), Type III(3), Type IV(2), TWR(3)
PQD	Quad Morstable Multi-vibrator	1							0.455	75	1A	ND	
RAD	Postamp Gain Adjust	1							0.088	90	1A	ND	
RBA	Ramp Clock Generator				1	1		1	0.05	175	1B	ND	Type 1-C(2), Type III(1), Type IV(2), TWR(2)
RBB	Integrator & Mode Selector	1							0.049	125	1A	ND	Type 1-C(1), Type III(1), TWR(1)
RBF	Gate, NAND	1	9	3					1.87	90	1A	STD	Type 1-C(1), Type III(6), Type IV(1), TWR(12)
REC	Comparator				1	3		2	0.086	100	1A	ND	Type 1-C(4), Type III(1), Type IV(3), TWR(4)
RRM	Prom			15					0.257	100	1A	MOD	Type 1-C(4), TWR(2)
SHU	Generator, Function (LSB)							2	1.72	285	1A	STD	Type 1-C(1)
SHV	Octant/Quadrant							2	1.07	310	1A	STD	Type 1-C(1)
SHX	Processor, Error, S/D							2	3.55	350	1B	STD	Type 1-C(1)
SHY	Generator, Function (MSB)							2	1.33	340	1A	STD	Type 1-C(1)
SQS	Clock Driver (1.5MHz)			1					1.22	125	1A	MOD	
TEZ	A. C. Filament Sense					2			0.01	200	1B	ND	Type 1-C(1), TWR(1)

(1) Status: STD–Standard; IP–In process of becoming standard; ND–New development for modular radar; SP–Special development for another program with no plans to qualify; MOD–Modification of existing module.

Key Code	Module Name	Location and Quantity: Receiver–Transmitter: 1,1 Receiver	1,2 Timing and Control	1,3 Bite	1,4 System Power Supply	1,5 Modulator Power Supply	3,1 Antenna Control Electronics	4,1 Display Electronic Unit	Estimated MTBF hours x 10^6	Estimated Cost	Size	Status(1)	Shared with Other MRP Systems
ADL	Resistor, pull-up		4	4			2	5	5.0	47.6	1A	STD	TWR(5)
AEA	AFC Output Scales 0 to +40 V	1							0.3154	100	1A	ND	Type 1-C(1), Type III(1), Type IV(1), TWR(1)
AEC	Transmitter Time Delay		1				1	1	0.2294	100	1A	ND	Type 1-C(1), Type III(1), Type IV(1), TWR(1)
AEH	8 Bit A/D or D/A Converter w/Sample and Hold			1			1	2	0.0361	175	1A	ND	Type 1-C(1), Type III)1), TWR(1)
AFD	Trigger Driver Assy		1						0.7997	125	1A	ND	Type 1-C(2), Type IV(1)
BBA	Counter, Up/Down Binary, Synchronous		1						0.345	72.25	1A	STD	Type 1-C(1), TWR(1)
BDL	Multiplexer, Digital	1	2	4			2	5	0.5	38.75	1A	STD	Type 1-C(7), Type III(1), TWR(5)
BED	Amplifier, Summing							2	3.45	85	1A	STD	
CDJ	High Voltage LC Filter				1			1	0.418	150	1B	ND	Type 1-C(1), Type III(1), Type IV(1), TWR(1)
CED	Over/Under Voltage Protector				1	1		1	0.044	100	1A	ND	Type 1-C(3), Type II(1), Type IV(3), TWR(2)
CFF	Video Buffer Amp. Line Driver	1							0.083	100	1A	ND	Type 1-C(5), Type IV(1), TWR(1)
CGK	AC Filter Program					1			0.085	175	1A	ND	
CGL	Driver, DC to DC Converter				1	3		2	0.146	125	1B	ND	Type 1-C(4), Type III, Type IV(3), TWR(4)
CMH/ CMZ	Test point	2	2	1	2		2	3	21.93	33.75	1A	STD	Type 1-C(7), Type (2), Type IV(5), TWR(6)
DPR	Power Supply				1	1		1	0.095	225	1G	ND	Type 1-C(1), Type III(1), Type IV(1), TWR(1)
D2F	Programmer Read Only Memory (32 X 24)		1						0.125	100	1A	ND	
D2G	Programmer Read Only Memory (32 X 16)		1						0.189	100	1A	ND	
EAB	Pull Up Resistor Network			1					0.866	100	1A	ND	Type 1-C(1), Type III(2), Type IV(1), TWR(1)
EGA	BITE Signal Conditioner	1		1		1		1	0.29	125	1A	ND	Type 1-C(2), TWR(2)
EHP	12-volt Regulator and Power Failure Reset			1					0.46	200	1A	ND	Type 1-C(1), TWR(1)
EHR	Computer Interface			1					0.118	125	1A	ND	Type 1-C(1), TWR(1)
EPM	Relay, DPDT		3					1	0.09	150	1A	–	
FAQ	Operational Amp Assy				1	2		2	0.028	150	1B	ND	Type 1-C(3), Type III(1), Type IV(3), TWR(3)
FAR	Output Over Voltage Over Current Limit				1	1		2	0.044	100	1A	ND	Type 1-C(1), Type IV(1), TWR(1)
FEG	High Voltage Positive Series Regulator	1			1			3	0.044	125	1B	ND	Type 1-C(2), Type III(1), Type IV(1), TWR(2)
FEH	Sample and Hold	1							0.514	150	1A	ND	Type 1-C(1), Type III(1), Type IV(1), TWR(1)
FFE	Regulator	1			4	3		4	0.084	200	1C	ND	Type 1-C(7), Type III(2), Type IV(1), TWR(7)
FHA	Triple 4-bit Binary Counter, Schottky		5					4	0.35	125	1A	1P	Type 1-C(9), Type III(4), Type IV(4), TWR(2)

(1) Status: STD–Standard; IP–In process of becoming standard; ND–New development for modular radar; SP–Special development for another program with no plans to qualify; MOD–Modification of existing module.

TABLE 9. RELIABILITY AND COST ESTIMATES OF DISCRETE COMPONENTS AND ASSEMBLIES

Component Name	MTBF-Hours	Cost-$
Microwave Unit		
AFC Preamp	105,000	400
Signal Preamp	111,000	500
Power Circuits	91,000	800
Microwave System	1,500	1,600
R/T Miscellaneous and Cabinet	20,000	6,500
Modulator Unit		
Modulator	37,037	2,000
Power Converter	17,857	1,500
Magnetron	2,198	1,000
ACE Miscellaneous	50,000	300
DEU Miscellaneous	10,000	452
Remote Radar Control	16,666	861
Display Control	9,756	550
Local Radar Control	15,268	630
Remote BITE	15,268	660
Pilot Radar Control	6,410	820
Junction Box #8	27,778	575
Junction Box #9	125,000	475
Indicator	2,460	7,861

Level	
1.0	APS-129 System
2.1	Receiver-Transmitter Unit
3.1.1	Receiver
3.1.2	Timing and Control
3.1.3	Built In Test (BITE)
3.1.4	System Power Supply
3.1.5	Modulator Power Supply
3.1.6	Microwave Unit
3.1.7	Cabinet and Miscellaneous Electronics
2.2	Modulator Unit
3.2.1	Modulator
3.2.2	Power Converter
3.2.3	Magnetron
2.3	Antenna Control Electronics Unit
3.3.1	Antenna Control SEMS
3.3.2	Enclosure and Miscellaneous Electronics
2.4	Display Electronics Unit
3.4.1	Display Electronics SEMS
3.4.2	Enclosure and Miscellaneous Electronics
2.5	Controls and Other Units
3.5.1	Remote Radar Control*
3.5.2	Display Control*
3.5.3	Local Radar Control
3.5.4	Remote BITE Control
3.5.5	Pilot Radar Control**
3.5.6	Junction Box #8
3.5.7	Junction Box #9
3.5.8	Indicator***

* Units 3.5.1 and 3.5.2 are only in the C-130/C-135 configuration

** Unit 3.5.5 is only in the C-141 configuration

*** The C-130/C-135 configuration requires two indicators. The C-141 requires only one.

FIGURE 4. WORK BREAKDOWN STRUCTURE OF THE APS-129 SYSTEM

TABLE 10. SYSTEM RELIABILITY ESTIMATES

WBS Identifier	RETROFIT PROGRAMS I. C-130/C-135	II. C-141	III. Combined
1.0	191.5	208.	193.5*
2.1	459.5	459.5	459.5
3.1.1	4151.1	4151.1	4151.1
3.1.2	5761.1	5761.1	5761.1
3.1.3	3507.2	3507.2	3507.2
3.1.4	4068.6	4068.6	4068.6
3.1.5	2063.6	2063.6	2063.6
3.1.6	1439.4	1439.4	1439.4
3.1.7	20000.0	20000.0	20000.0
2.2	1858.9	1858.9	1858.9
3.2.1	37037.0	37037.0	37037.0
3.2.2	17857.0	17857.0	17857.0
3.2.3	2198.0	2198.0	2198.0
2.3	6561.8	6561.8	6561.8
3.3.1	7553.0	7553.0	7553.0
3.3.2	50000.0	50000.0	50000.0
2.4	380.4	380.4	380.4
3.4.1	905.6	905.6	905.6
3.4.2	10000.0	10000.0	10000.0
2.5	869.1	1355.8	910.9*
3.5.1	16666.7	------	16666.7
3.5.2	9756.1	------	9756.1
3.5.3	15267.9	15267.9	15267.9
3.5.4	15267.9	15267.9	15267.9
3.5.5	-------	6410.3	6410.3
3.5.6	27777.8	27777.8	27777.8
3.5.7	125000.0	125000.0	125000.0
3.5.8	1229.7	2459.5	2459.5

* Weighted average of Programs I and II

NOTE: The reliability of units 3.1.1 thru 3.1.5, 3.3.1, and 3.4.1 represents SEM technology. In toto, these units represent 46% of the system failure rate of configuration I (49% of configuration II).

will be noted. The percentage of the system failure rate attributable to SEM's, as noted in Table 10 is between 46 and 49%. Implications of these values will be discussed in a sensitivity analysis case.

Retrofit Program Data

In the statement of work for this study, two basic retrofit programs to be evaluated were identified as:

(1) Installation of a navigator operable system in C 130/C 135 aircraft

(2) Installation of a pilot operable system in C 141 aircraft.

These programs were evaluated separately (hereafter noted Programs I and II) and as a combined program (Program III). Thus, baseline data were shown in Table 11. Usage data reflect each program separately and a weighted average of the combined forces. The force basing structure was extracted from the APN-59X study[7] as that analysis was performed in support of an actual retrofit/ modernization decision process.

Life Cycle Cost Analysis Procedure

The life cycle cost analyses were performed using the Generalized Electronics Maintenance Model (GEMM)[46]. GEMM is an integrated design and logistics support analysis model written in FORTRAN IV computer language. It was developed by the U. S. Army Electronics Command and has been used by several components of the Army. While it was originally developed by and for the Army, it is a very flexible model and is adaptable to Air Force deployment concepts. Through an earlier research effort at Battelle, it has been recommended for application to Air Force avionics repair level decision making.[47] This section will briefly describe the model.

By classification, GEMM is an analytical model. This means that (1) data variables and calculation procedures are prescribed by the users input; (2) the model exercises discrete equations; and (3) the results are mathematically summed.

The most significant characteristics of the GEMM model are that:

- It considers up to four levels of indenture (e.g. end item, line replaceable unit, shop replaceable unit, and parts).
- It allows commonality of parts among different SRU's and LRU's
- It can aggregate the reliability of higher level assemblies given the piece part count and piece part reliability.

TABLE 11. FORCE STRUCTURE INFORMATION

	RETRO FIT PROGRAMS		
	I. C 130/C 135	II. C 141	III. COMBINED
Aircraft	1,900	276	2,176
Annual Flying Hours (Force)	859,272	257,112	1,116,384
Average Hours Per Operating Day	1.81	3.90	2.07*
Number of Maintenance Levels			
Organizational	120	9	129
Base	100	9	100**
Depot	1	1	1

* Weight Average of Programs I and II

** Base Level Number Does not Differ Between I and II Because Both C 130 and C 141 Forces are Operated by the Military Airlift Command and the Base Levor Shops would be Shared.

- It can evaluate up to 35 predefined maintenance policies or a specific user defined policy.
- It can be easily used to run an indefinite number of sensitivity cases by adding additional data cards to the data deck.

These characteristics were appropriate for the APS-129 radar study requirements, particularly the first two.

The model requires the following categories of input information:

- Reliability and maintainability factors for the specified design configurations (parts, assemblies, LRU's, end items).
- Research and development costs
- Acquisition costs
- Force structure
- Test equipment (dedicated or shared)
- Personnel (dedicated or shared)
- Attrition factors
- Transportation
- Stockage information
- Economic life

The R&D costs are a throughput and are used only in the final.

Those inputs for GEMM which were used in this study but are not design dependent are listed in Table 12. These are primarily data related to stockage calculations and were established to be compatible with the analysis reported in Reference 7. In the following paragraphs, the assumptions used in formulating the design related data for the LCC analysis are stated. As appropriate, supporting documents are referenced.

Research and Development

As noted in Tables 6 and 8, 73 SEM module types in the design are new development. Using the vendor design cost estimates provided by NAFI[20], a development cost of $19,400 per module was assumed. This represents the cost to document the design from the current advanced development status to a producible item. It does not include estimated vendor costs for qualification costs. Those costs will be addressed as a sensitivity issue. Thus, the baseline R&D costs are consistent with the baseline reliability estimates which do not reflect the higher SEM reliability numbers which NAFI contends are achievable (and have been demonstrated) through SEM qualification procedures.

TABLE 12. INPUTS FOR LCC ANALYSIS WHICH ARE NOT DESIGN DEPENDENT

Data Item				Value Used
Transportation Time				
Organizational - Base				.5 hrs
Base - Depot				120 hrs
Transportation Cost				$.53/lb
Requisition Time (hrs)	Parts	Assemblies	LRU's	
Organizational	120	120	240	
Base	120	120	240	
Depot	4	4	6	
Wait Time for Repair				
Organizational				1 hr
Base				2 hrs
Depot				72 hrs
Productivity Factor				
Depot				1.
Other				.5
Safety Stock				
Sigma				1.29
Probability				.90
Reorder Period				9 months
Stockage Objective Period	Discards	Repairables		
Base	1 month	10 days		
Depot	3 months	.5 months		
Turnaroudn Time				
Base	4 days			
Depot	1.5 months			

The baseline R&D total of $1.916 million is assumed constant across all retrofit programs. It represents 73 times the per module cost plus an estimated $.5 million for the development of the rest of the system.

Acquisition Costs

The system acquisition costs were estimated by "rolling up" the SEM Costs, the card cage costs, the costs of the discrete components, and the assemblies. These sums were increased by 15% for G&A and fee (this amount was used on the basis of Reference 43). These sums were then adjusted for the quantities procured using a 90% progress (or "learning") curve. The basic costs, and quantity adjusted costs, of the first three levels of the WBS are tabulated in Table 13.

Retrofit Costs

As noted earlier, it has been estimated that 350 manhours per aircraft would be required to retrofit the C 141 aircraft with a radar which was not LRU compatible with the APN-59 installation. That system, however, would also require antenna replacement and completely new mounting equipment. For this analysis, it was assumed that retrofit of the APS-129 design in the C 141 would not require class A kits (adaptors) and would require only 75% of the 350 hours. For the C 130/C 135 force, the basic amount was decreased by 25 hours per aircraft to reflect the absence of the pilot operable conversion. The retrofit program costs were estimated by multiplying the resulting man-hours by $20 per hour (a planning factor used by Warner Robins).

Support Equipment Costs

The support equipment costs were estimated on the basis of two levels of test stands. At the base level, a hot bench mock-up would be used. The cost is estimated to be the basic level 1 system cost plus $10,000 to adjust for special connectors and test point adaptors. The depot level set was assumed to be similar except with an additional $20,000 adjustment to allow for more diagnostics. These stands are considered to be required in addition to the built in test equipment because of the basic LRU remove and replace concept of Air Force maintenance. Once an LRU is removed, is must be reinserted in a BITE equipped test stand (i.e. hot bench mock-up) for diagnostics to continue. In addition to acquisition costs, the annual support cost of the test equipment was estimated at 7% of the acquisition cost. (This, too, is a common planning factor used by Warner Robins personnel). Thus, the test equipment costs fluctuate on the basis of both force structure and life time.

TABLE 13. ACQUISITION COSTS FOR THE SYSTEM AND LINE REPLACEABLE UNITS

	Initial Estimate*	DOLLARS PER UNIT Quantity Adjusted Estimates** 276	1900	2176
1.0 (C 130/C 135 System)	79,970	--	72,536	71,056
1.0 (C 141 System)	71,518	86,975	--	--
2.0 R/T	35,015	42,583	31,760	31,112
2.2 Modulator	4,500	5,473	4,082	3,998
2.3 Antenna Control	3,975	4,834	3,605	3,534
2.4 Display Electronics	17,007	20,683	15,426	15,111
3.5.1 Radar Control	861	1,047	781	765
3.5.2 Display Control	550	669	499	489
3.5.3 Local Control	630	--	571	--
3.5.4 Remote Bite	660	--	599	--
3.5.5 Pilot Control	820	997	--	--
3.5.6 Junction Box	575	699	522	511
3.5.7 Junction Box	475	578	431	422
3.5.8 Indicator	7,861	9,560	7,130	6,985

*Basic quantity of 1000

**Assumed 90% progress curve

Spares

Initial and replenishment spares were calculated by the GEMM model using factors listed in Table 12. Values for this factors were cross checked with sparing factors used at Warner Robins for the APN-59X study.(57)

Initial spares should remain relatively constant. This is due to the model's algorithm that accounts for integer levels of each sparable item. For example, requirements for .4 and .6 spares per base, respectively, of two items will be costed as one of each. If, based on an increased level of system usage, the calculated requirements become .6 and .9 respectively, the level is still costed one each. The multiple usage of identical SEMs throughout the design should be a distinct advantage in this respect.

Manpower Costs

Maintenance action times were estimated using engineering judgement after a careful inspection of the fabricated APS-129 set.

The estimated repair times are as shown in Table 14. Cost factors used are as shown in Table 12. Organizational and base level maintenance manpower were accounted for on a man-hour basis. The assumption was made that the personnel would possess general avionics Air Force Specialty Codes. After initial electronics training, on-the-job-training would qualify the personnel to work on the weapon system avionics. However, for depot level, it was assumed that specific, specialized training would be required (obtained through on-the-job-training after the initial course). Therefore incremental, integer accounting was used for depot manpower. The effects of these accounting assumptions was investigated by a sensitivity analysis case.

Training Costs

Training cost estimates provided by AFAL were used for initial training set-up ($45,000) and maintenance personnel training (80,000). It was assumed that the turnover rate would be 50%. Thus, equivalent retraining costs would be expected 4, 7.5 and 10 times, respectively, during the 10, 15 and 20 year programs.

Transportation Costs

Transportation costs were accumulated by the GEMM model at a rate of $.53 per pound of equipment shipped (AFLC estimating factor).

TABLE 14. BASELINE REPAIR TIME ESTIMATES (Hours)

WBS Identifier	Time to Checkout	Time to Fault Isolate & Replace	Time to Repair
1.0	.2	.75	
2.1	1.3		
3.1.1		.5	
3.1.2		.5	
3.1.3		.5	
3.1.4		.5	
3.1.5		.5	
3.1.6			3
3.1.7			3
2.2	1.2		
3.2.1			2
3.2.2			3
3.2.3		1	
2.3	.6		
3.3.1		.5	
3.3.2			1.5
2.4	.6		
3.4.1		.5	
3.4.2			1.5
2.5	.5		
3.5.1			6
3.5.2			6
3.5.3			6
3.5.4			6
3.5.5			6
3.5.6			4
3.5.7			4
3.5.8			8

Other Costs

Publication and technical order costs were considered to be negligible. Inventory management cost of SEM's were considered to be absorbed by DESC. Other inventory costs were considered negligible.

Results of the Baseline LCC Analysis

The results of the baseline analysis, for the three retrofit programs, are shown in Table 15 for ten, fifteen and twenty year periods. For the majority of the sensitivity analyses, the fifteen year case for Program I is considered the basic reference point. The following observations are made about the results in Table 15:

1. The acquisition costs, by far, represent the largest portion of the estimated APS-129 life cycle costs.
2. The spares cost represent the next largest segment and, as expected, the replenishment spares costs are directly sensitive to life time.
3. The manpower and training categories are relatively insignificant in the baseline estimates using the assumptions of non dedicated personnel at the organizational-and base-levels.

Sensitivity Analysis

The baseline life cycle cost analysis was formulated using two categories of assumptions. The first category involves operational and logistics factors. The second category involves design factors. In the following paragraphs, results of six sensitivity analyses are presented. These analyses were performed in order to assess the degree of change to the baseline results when the values of operational or design related parameters are changed.

System Usage

One of the most important assumptions for a logistics analysis is the forecasted usage (i.e. flying hours) over the period of interest. The GEMM model calculates logistic resource requirements on the basis of expected operating hours per day. It was assumed that the aircraft would be used 250 days per year. From this usage, the daily use was calculated from the annual flying program data, as shown in Table 11. To evaluate the impact of lower and higher utilization rates, three additional values for the operating hours per day variable were tested. The results are shown in Table 16. For Program I, 3 hours of aircraft operation per day represents a 66% increase from the nominal value of 1.8 hours. However, the LCC of the APS-129 increases only 9.32%. Similar results are indicated by the other Programs. The relative insensitivity of the results to operational usage is attributable to the integer accounting for sparable items in the model and the use of non-dedicated manpower at the first two levels of maintenance.

TABLE 15. BASELINE LIFE CYCLE COSTS - $ MILLIONS

	C 130/C 135			II. C 141			III. COMBINED		
PROGRAM LIFE	10	15	20	10	15	20	10	15	20
COST CATEGORY									
Research and Development	1.916	1.916	1.916	1.916	1.916	1.916	1.916	1.916	1.916
Acquisition	137.819	137.819	137.819	24.005	24.005	24.005	152.545	152.545	152.545
Retrofit	9.263	9.263	9.263	1.029	1.029	1.029	10.292	10.292	10.292
Support Equipment	10.521	15.782	21.042	1.331	1.997	2.663	10.328	15.492	20.657
Spares	30.127	36.468	42.811	6.178	8.029	9.881	33.885	41.687	49.487
Initial	(18.382)	(18.382)	(18.382)	(2.743)	(2.743)	(2.743)	(19.439)	(19.439)	(19.439)
Replenishment	(11.745)	(18.086)	(24.429)	(3.435)	(5.286)	(7.138)	(14.446)	(22.248)	(30.048)
Manpower	.854	1.281	1.708	.383	.575	.767	1.064	1.596	2.128
Training	.445	.645	.845	.125	.165	.205	.445	.645	.845
Transportation	.762	1.142	1.523	.240	.360	.480	1.009	1.513	2.017
Total	191.707	204.316	216.927	35.207	38.076	40.467	211.484	225.686	239.887
System MTBF(hours)	191.5	191.5	191.5	208	208	208	193.5	193.5	193.5
Effective MTBF*(hours)	181.9	181.9	181.9	197.5	197.5	197.5	183.8	183.8	183.8

* Reflects Adjustment for False Pull Factor -5% Nominal

TABLE 16. LCC SENSITIVITY TO OPERATIONAL USAGE
($ MILLIONS)

Retrofit Program	I.			II.			III.		
Usage Per Day*	1	2	3	3	4	5	1	3	5
Cost Categories Affected									
Spares	27.680	38.488	54.093	6.720	8.200	10.069	28.766	59.147	84.918
Initial	17.679	18.504	24.125	(2.631)	(2.752)	(3.260)	(18.012)	(26.914)	(31.203)
Replenishment	(10.001)	(19.984)	(29.968)	(4.089)	(5.448)	(6.809)	(10.754)	(32.233)	(53.715)
Manpower	.828	1.387	1.946	.506	.585	.663	.911	2.192	3.743
Transportation	.631	1.262	1.894	.278	.371	.463	.731	2.193	3.654
Sum of Other Categories	165.425	165.425	165.425	29.112	29.112	29.112	180.89	180.89	180.89
Total	194.564	206.562	223.358	36.616	38.268	40.307	211.298	244.422	273.205
% Change**	-4.77	+1.10	+9.32	-3.83	+.50	+5.86	-6.38	+8.30	+21.06
System MTBF(hours)	191.5	191.5	191.5	208	208	208	193.5	193.5	193.5
Effective MTBF(hours)	181.9	181.9	181.9	197.5	197.5	197.5	183.8	183.8	183.8

* Nominal values for each program: 1.81, 3.83, 2.07, respectively
** Per cent change from baseline 15 year LCC in Table 12

Apportionment of Personnel

In the baseline analysis, it was assumed that the maintenance personnel at the first two levels of maintenance (organizational and base levels) would be general avionics technicians and their costs could be accumulated on a man-hour basis. Sensitivity of this assumption was tested by considering the cost of maintenance technicians dedicated to APS-129 repair at each level. Under this assumption the annual cost of the technician would be charged to APS-129 repair, regardless of level of activity. The results of this analysis, conducted on Program I only, are presented in Table 17. The results indicate that the apportionment of personnel is one of the most sensitive assumptions made in the baseline analysis. If dedicated personnel were required at each level, manpower costs would represent 12.2% of the LCC instead of the .6% shown in Table 15.

Discard Versus Repair

Discard of failed SEMs is a key element of the SEM maintenance philosophy. Sensitivity of the discard versus repair decision for the SEM's was investigated through a detail analysis of the Antenna Control Electronics (ACE) unit. The ACE consists entirely of SEMs and SEM connectors. It was assumed that either all SEMs were repairable or all were to be discarded. This assumption was made on the basis that once procedures and support equipment were developed for the more expensive SEMs, the marginal investment in making all SEMs repairable would probably be feasible. Evaluation of a unit (the ACE) made up of SEMs was done because it is that level of indenture which would be removed and replaced under an Air Force maintenance policy. Table 18 presents the results of the ACE analysis using baseline Program I operational factors. The results imply that discard of the module after removal is most efficient.

Repair Level Sensitivity

The predominant influence of level of repair decisions are on the spares, transportation and manpower categories of costs. In the Discussion Section, the incompatibility of the Navy's standard maintenance philosophy for SEMs (fault isolate to SEM in-place) with Air Force Avionics maintenance was addressed. However, it was considered to be of interest to calculate the impact of such a policy. The results this analysis are shown in Table 19. In the analysis, it was assumed that fault isolation would result in removal of only the failed module. This is the most optimistic assumption possible and, therefore, the 4.25% decrease in LCC, as shown in Table 19, is indicative of a best case situation. It is assumed that in reality, successive replacement of SEM's, in the group identified by the BITE, would occur until operability was restored. It is doubtful that the technician would fault isolate to the single failed SEM.

TABLE 17. LCC SENSITIVITY TO DEDICATED MANPOWER
($ Millions)

Retrofit Program		I	
Number of Dedicated Manpower Types*	0	2	3
Cost Category Affected			
Manpower	1.135	15.850	28.171
Sum of Other Categories	203.035	203.035	203.035
Total	204.170	218.885	231.206
% Change	+0.07	+7.13	+13.16
System MTBF(hours)	191.5	191.5	191.5
Effective MTBF(hours)	181.9	181.9	181.9

*Nominal value is 1 (Depot Level); Maximum value is 3.

TABLE 18. SEM DISCARD VERSUS REPAIR FOR ANTENNA CONTROL UNIT
($ millions)

	POLICY 1: • Isolate to Module at Organizational Level • Repair at Depot	POLICY 2 • Isolate to Module at Base Level • Repair at Depot	POLICY 3 • Isolate to Module at Base Level • Discard
COST CATEGORIES AFFECTED			
Test Equipment	3.357	2.947	2.051
Spares	.413	.779	1.318
Initial	(.373)	(.739)	(1.021)
Replenishment	(.040)	(.040)	(.297)
Manpower	.299	.299	.030
Total	4.069	4.025	3.399

TABLE 19. LCC SENSITIVITY TO REPAIR LEVEL*
($ millions)

Retrofit Program	I	II
Cost Categories Affected		
Spares	27.147	7.773
Initial	(9.009)	(2.506)
Replenishment	(18.138)	(5.267)
Manpower	1.082	.511
Transportation	1.974	.579
Sum of Other Categories	165.425	29.112
TOTAL	195.628	37.975
% Change	-4.25	-.27
System MTBF(hours)	191.5	191.5
Effective MTBF(hours)	181.9	181.9

*Fault isolate and replace SEMS on-equipment, repair other equipment at depot level

BITE Confidence

A phenomenon that has influenced logistic support costs of avionics systems is the false pull ratio. Another term used to describe this factor is the frequency of "cannot duplicate" maintenance actions. Whatever the term, maintenance and supply resources are consumed. Therefore, the degree of confidence in the BITE to correctly sense a failure, and isolate it properly, is a key design parameter. The influence of this design parameter was evaluated by adjusting the reliability of the first two levels of the WBS. The results of this analysis are presented in Table 20. For Program I, a 30% false pull rate would imply a system level MTBF of 134 hours and result in a .15% growth in the life cycle costs. This low impact is reflected because the spares requirement were already rounded-up to integer quantities. In Program II, a 30% false pull ratio was large enough to increment the spares requirements and the impact is 1.18%.

SEM Reliability Increases

The costs, and benefits, of conforming to the SEM Program qualification and quality assurance procedures were not included in the baseline analysis. A sensitivity analysis was performed to assess the impact of higher R&D costs and higher SEM reliability resulting from such conformance. It was assumed that an additional cost of $2.09 million would be incurred for qualification of the non-standard SEMs. In return, it was assumed that SEM reliability would increase by a factor of ten. For this analysis, results are presented for reliability improvement factors of 5 and 10.

It was noted earlier in the discussion of the system reliability, that the SEMs in the APS-129 design accounted for only 46-49% of the system failure rate. Because of this, the increase in SEM reliability does not have as much impact at the system level as it would have if the proportion was higher. The adjusted system level MTBFs are presented in Table 21 and the results of including the higher MTBF's in the LCC analysis are presented in Table 22. The results indicate that LCC reductions are achieveable.

Conceptual Design Alternatives

In the course of the Design Review and Analysis processes, two design alternatives were conceptualized and their life cycle costs evaluated. The two share a common goal of improving the interface of the SEM technology with the typical Air Force Avionics maintenance philosophy. They were postulated in order to project the impact of feasible design alternatives for further detailed analysis during any subsequent development activities.

TABLE 20. LCC SENSITIVITY OF BITE CONFIDENCE
($ MILLIONS)

Retrofit Program	I.			II.		
Probability of False Pull*	.1	.15	.3	.1	.15	.3
Cost Categories Affected						
Spares	N/A	N/A	N/A	N/A	10.345	10.345
Initial					(5.059)	(5.059)
Replenishment					(5.286)	(5.286)
Manpower	1.327	1.378	1.577	.589	.604	.664
Sum of Other Categories	203.035	203.035	203.035	39.434	29.472	29.472
Total	204.362	204.413	204.612	40.023	40.021	40.481
% Change	+ .02	+0.05	+.14	+.04	+1.03	$1.18
System MTBF(hours)	191.5	191.5	191.5	208	208	208
Effective MTBF(hours)	172.4	162.8	134	187.1	176.7	145.5

TABLE 21. SYSTEM EFFECTS OF INCREASED SEM RELIABILITY

	(Hours) MTBF Of WBS Elements			
Retrofit Program	I		II	
Multiple of SEM Reliability	5X	10X	5X	10X
System	323.82	354.4	373.8	415.2
Receiver-Transmitter	968.8	1,124.6	968.8	1,124.6
Modulator	N/A*	N/A	N/A	N/A
Antenna Control	21,514.9	30,084.5	21,514.9	30,084.5
Display Electronics	3,116.8	4,752.3	3,116.8	4,752.3
Controls	N/A	N/A	N/A	N/A

TABLE 22. LCC SENSITIVITY OF INCREASED SEM RELIABILITY
($ millions)

Retrofit Program	I		II	
SEM R Multiple	5X	10X	5X	10X
Cost Categories Affect				
R&D	4.006	4.006	4.006	4.006
Spares	31.958	31.189	6.317	5.783
Initial	(17.685)	(17.391)	(2.231)	(1.848)
Replenishment	(14.273)	(13.798)	(4.086)	(3.935)
Manpower	.786	.729	.420	.402
Sum of Other Categories	164.651	164.651	27.556	27.556
Total	201.401	200.575	38.299	37.747
% Change	-1.43	-1.83	-4.27	-5.65
System MTBF (hours)	323.8	354.4	373.8	415.2
Effective MTBF (hours)	307.6	336.7	355.1	394.4

Reorientation of BITE

This concept focused on removing the BITE subsystem in each R/T cabinet but retaining the interfaces. The BITE Hardware would be incorporated in the shop level hot bench mock-up. The effects of such a change would be reduced acquisition costs and improved system reliability by removing WBS units 3.1.3 and 3.5.4. Another effect would be an increase in the false pull rate. In recognition of the implications of no BITE on equipment, several different analyses were conducted and the results are shown in Table 23. The first three columns of Table 23 indicate the percentage change from baseline data in Table 15. The remaining five columns reflect the changes from the 15 year, no-BITE baseline in the left most column of Table 23. The results indicate that reorientation of the BITE would have economic advantages.

Reconfiguration of the Receiver-Transmitter Cabinet

The current configuration of the RIT cabinet places the five assemblies of SEM's (BITE, timing and control, receiver, system power supply, and modulator power supply) in four locations internal to the cabinet structure. This physical layout is compatible with the standard shipboard maintenance environment and shop level activities. However, it was the common evaluation of this study team that it was not ideally suited for avionics bay removal and replacement of SEM's. An alternative concept for the R/T cabinet was postulated and a sketch is shown in Figure 5. This concept involves five separable assemblies of SEM's (conceptually the five functional groups identified above) mounted on an R/T base unit. Two effects of such a configuration would be that each assembly becomes a separate line replaceable unit; and that the heat dissipation problem in the R/T cabinet cavity is reduced by exposing each SEM assembly to ambient air. The latter effect could potentially improve the system reliability but this was not included in the analysis presented in Table 24. In addition, the on-equipment BITE would only be required to fault isolate to the failed assembly and should be less expensive. However, the full level of BITE was included in the acquisition costs. The reduced LCC resulting from this configuration is primarily the result of fewer spare R/T units in the pipeline. Similar results would be expected from the analysis of the reconfigured R/T in the other retrofit programs.

TABLE 23. LCC SENSITIVITY OF NO ON-EQUIPMENT BITE - $ MILLIONS

	RETROFIT PROGRAM I ONLY			Usage	Usage	Usage	5 Times	10 Times
	Base, 15 years	10 Years	20 Years	1 Hour/Day	2 Hour/Day	3 Hour/Day	SEM R	SEM R
Cost Categories Affected								
R&D							4.006	4.006
Acquisition	123.896	123.896	123.896	123.896	123.896	123.896	123.896	123.896
Spares	34.166	27.996	40.367	25.576	36.140	52.460	30.048	29.374
Initial	(16.483)	(16.483)	(16.483)	(15.799)	(16.601)	(23.159)	(15.882)	(15.646)
Replenishment	(17.683)	(11.483)	(23.884)	(9.777)	(19.539)	(29.301)	(14.166)	(13.728)
Manpower	1.466	.977	1.955	.931	1.592	2.253	.760	.711
Transportation	1.142	.762	1.523	.631	1.262	1.893	---	---
Sum of Other Categories	27.606	22.145	33.066	27.606	27.606	27.606	26.832	26.832
Total	188.276	175.746	200.807	178.640	190.496	208.108	185.542	184.819
% Change.	-7.85*	-8.33*	-7.43*	-5.12**	+1.18**	+10.53**	-1.45**	-1.84**
System MTBF(hours)	208.1	208.1	208.1	208.1	208.1	208.1	344.8	375.66
Effective MTBF(hours)	145.7	145.7	145.7	145.7	145.7	145.7	327.6	356.9

* % change from Program 1 baseline in Table 15 for appropriate life
** % change from no-BITE baseline (left most column)

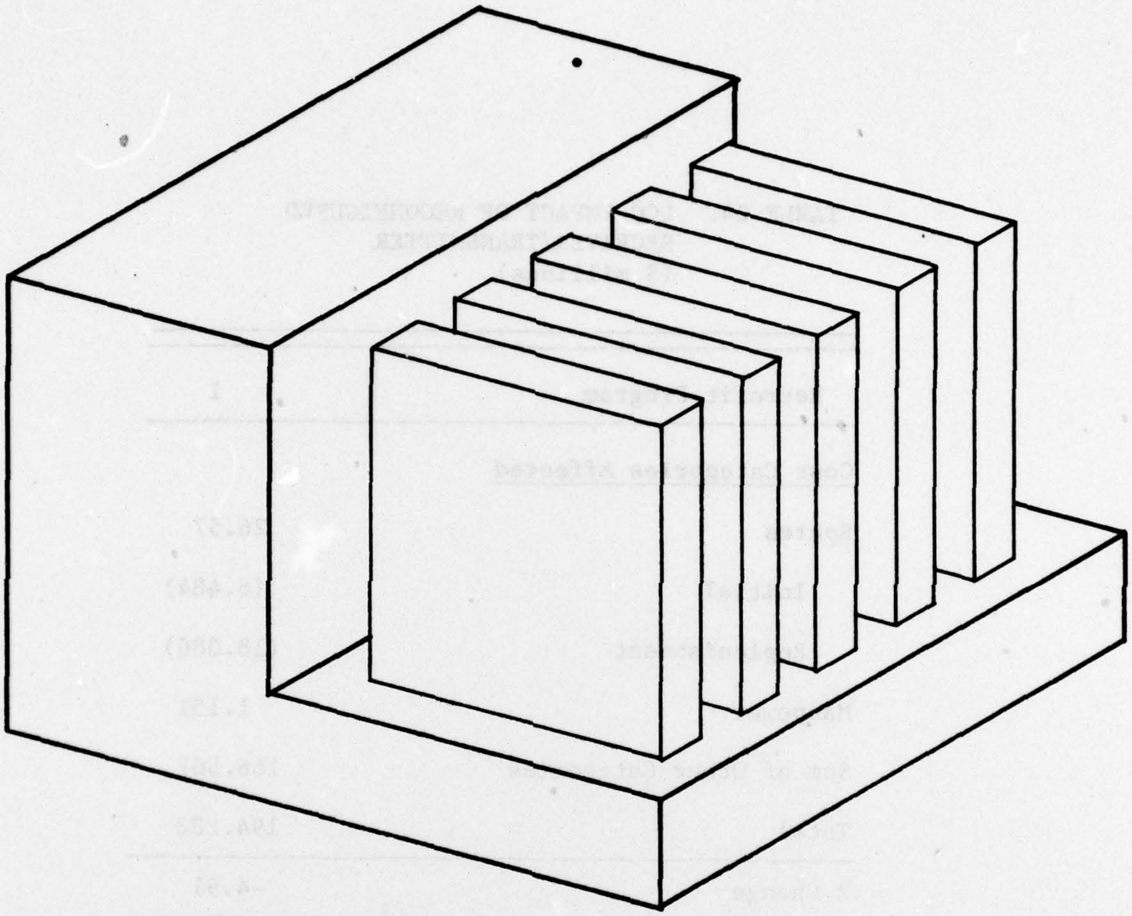


FIGURE 5. CONCEPT OF RECONFIGURED R/T UNIT WITH FIVE SEPARABLE SEM ASSEMBLIES

TABLE 24. LCC IMPACT OF RECONFIGURED RECEIVER/TRANSMITTER ($ millions)

Retrofit Program	I
Cost Categories Affected	
Spares	26.57
Initial	(8.484)
Replenishment	(18.086)
Manpower	1.151
Sum of Other Categories	166.567
Total	194.288
% Change	-4.91
System MTBF(hours)	191.5
Effective MTBF(hours)	181.9

FINDINGS AND CONCLUSIONS

This section restates the important findings of the qualitative evaluation described in the Discussion Section and the quantitative analysis presented in the Analysis Section. Two conclusions are then formulated on the basis of these findings.

Findings

The qualitative findings of this study include:

(1) The Standard Electronic Module Program offers design and logistics engineers an alternative which provides protection from the potential economic and technological obsolescence of discrete components.

(2) The APS-129 design demonstrates that commonality of functional electronic modules in ground, shipboards, and avionic systems can be achieved.

(3) The APS-129 design demonstrates that incorporating SEM technology incurs a weight and volume penalty. However, the degree of this penalty would be subject to reduction if further development continued.

(4) The APS-129 design demonstrates that the SEM technology can be packaged for the avionics environment. However, the current physical configuration of the receiver-transmitter cabinet does not optimally interface with standard Air Force maintenance and supply procedures.

(5) The APS-129 design includes a built-in-test capability which does not optimally interface with standard Air Force maintenance procedures.

The quantitative findings of this study include:

(1) The system reliability estimates and the percentage of the system failure rates attributable to SEM technology, for the two configurations are:

	MTBF(hours)	Portion Attributable to SEM's
C130/C135	191.5	46%
C141	208	49%

(2) The estimated life cycle costs for the three retrofit programs are:

	10 years	15 years	20 years
C130/C135	$191.7M	$204.3M	$216.9M
C141	$ 35.2M	$ 38.1M	$ 40.5M
COMBINED	$211.5M	$225.7M	$239.9M

(3) The life cycle cost estimates are influenced by both design dependent and operational usage dependent parameters. Both types of parameters were evaluated through analysis of the results and sensitivity studies. A summary of these findings follow:

(a) Of the design dependent parameters, acquisition and retrofit costs dominate the LCC estimates.

(b) Of the usage dependent parameters, the factors determining the requirements for spares and support equipment significantly effect the LCC estimates.

(c) Maintenance manpower costs appear significant (12% of LCC) only when all levels of maintenance are assumed to have dedicated APS-129 technicians.

(d) Repair of SEM's, in lieu of discard, does not appear justifiable.

(e) Replacement of SEM's on board the aircraft could potentially reduce the LCC estimates. However, reorientation of the built-in-test capability for removal of SEM's at the shop level of maintenance would have a larger decrease in the LCC.

(f) Reconfiguration of the APS-129 receiver-transmitter cabinet, so that the SEM's are enclosed in five line replaceable units, would improve the logistics interface of the design with Air Force maintenance procedures.

Conclusions

The primary conclusion of the study team is that there exist design alternatives for the APS-129 which could improve the interface of the SEM technology with Air Force maintenance policies and procedures. A secondary conclusion is that the SEM concept offers positive potential as a life cycle cost and logistics supportability oriented design technology.

APPENDIX A

THE STANDARD ELECTRONIC MODULE PROGRAM

APPENDIX A

THE STANDARD ELECTRONIC MODULE PROGRAM

The Standard Electronic Module Program (SEMP) originated in 1962 as the U. S. Navy's Standard Hardware Program. It is now a tri-service program with the following organizations involved:

- o Defense Electronics Supply Center (DESC), Dayton, OH as the tri-service coordinator
- o Naval Electronics Systems Command as the technical management activity
- o Naval Avionics Facility Indianapolis (NAFI) as the design review activity
- o Naval Weapons Support Center (NWSC-Crane) as the quality assurance activity
- o Naval Electronics Laboratory Center as the R&D activity

The basic thrust of SEMP is to develop a family of electronic modules which are standardized in physical dimensions and electronics functions. The objective is to achieve high reliability, low-cost modules which will be common across multiple electronic systems. The goal is to achieve reduced life cycle costs by:

(1) Reducing lead time required to develop new systems.

(2) Reducing support costs through higher reliability and discard-at-failure maintenance.

(3) Allowing open market competition for procurement of replenishment spare parts.

The hardware aspects of the program have taken the form of a standard module which is 2.62 inches wide, 1.95 inches high, and 2.90 inches thick. Figure A-1 identifies the major features of the standard 1A size module. The interface of the SEM with mounting hardware is strictly defined and controlled. Standard mounting hardware components have been developed and are referred to as SEM card cages. These cages are compatible with module sizes with multiples in the thickness dimension. In addition to growth in thickness, the SEMP allows double width modules. However, no growth in the vertical dimension is permitted.

Partitioning of electronic functions into SEM size circuits which have potential for multiple system usage is seen as the crucial test in application of the SEMP technology. When designing a system, the system must initially be partitioned into functional circuit blocks. Then the SEM functional level is primarily determined by the number of components needed to perform the function within the circuit board area and keep the cost relaitvely low. As shown in this study, it is also important the modular be at the next higher assembly level. Efficient modularization at the circuit card level does not guarantee efficient modularization at the line replaceable unit level.

As the SEMP has evolved, and the roles of the organizations have grown, the advantages which it offers include:

(1) production quality control through NWSC-Crane activities

(2) established and qualified reliability specifications and tests

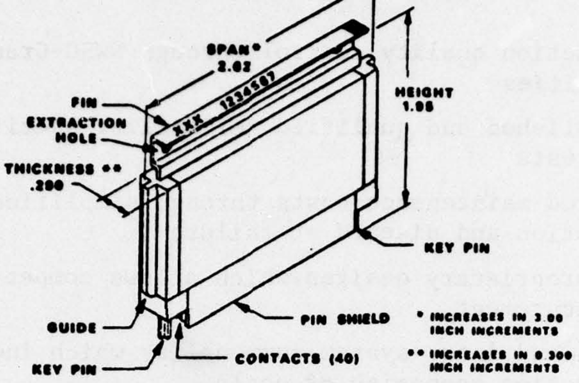
(3) reduced maintenance costs through simplified fault isolation and discard at failure

(4) non-proprietary designs which allows competitive reprocurement

(5) intra-and inter-system commonality which increases production economies of scale.

However, there are tradeoffs which have to be considered, particularly in avionics systems which are traditionally designed to very strict volume and weight constraints. Two disadvantages to SEM's in avionics, therefore, are the comparatively low density electronic packaging and the extensive cabling required.

The SEMP references noted in the main body of the report document the many aspects of the SEMP concepts and applications. Of most general use is, perhaps, the MIL Handbook 246, SEM Program Management Guide. For consideration of economic factors, reference 28 is perhaps the best document which has unlimited distribution.



MODULE MECHANICAL REQUIREMENTS

FIN - Provides the marking surface, extraction interface, and thermal interface for heat dissipation for SEM modules.

EXTRACTION HOLES - Provide the common interface by which modules are removed by means of an extraction tool.

GUIDE - Provides a surface for guiding the module into the mating connector and mounting structure, as well as a thermal interface for heat dissipation. Each module increment has a set of guide structures.

CONTACTS - Male contact pins based on the 0.100 of an inch grid system form the module connector. Each module increment may have a maximum of 40 contacts per module increment.

PIN SKIRTS - Provide a convenient protective and marking surface for module contacts.

KEY PINS - Provide the means of uniquely polarizing modules of different functions to ensure that they are not wrongly inserted into the mounting structure. A three-letter key code defines the configuration and rotational positions of two uniquely configured keying pins inserted into each module header surface. SEM modules having the same key code must be both mechanically and electrically interchangeable with each other.

FIGURE A-1. PARTS OF A TYPICAL SEM MODULE(8)

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